Approaching nano-spaces : 1-DOF nanomanipulator

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705

APPROACHING NANO-SPACES: 1-DOF NANOMANIPULATOR

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Abstract
Different scientific fields like biology or physics develop applications where a successful nano-object manipulation is peremptory. In the aim of realizing a useful multi-sensory interface allowing thus, human presence in the nano-world, we present in this paper the first results from the one - degree of freedom (DOF) nano-manipulator developments that connects an Atomic Force Microscope (AFM) with our Force Feedback Gestural Device (FFGD). The application of the AFM-FFGD coupling contains a redefining of the real-time remote-control handling, bringing in the concept of mixed reality. The designed models described in this paper represent the basics of the virtual reconstructions of a nano-scene.

1. Introduction

The actual tendencies in nanotechnology are pointed for creating more and more advanced nano-manipulators that are requested in many applications [1, 2]. Fields like: *biology* [3] where a convivial tool to manipulate directly the alive materials at a nano-scale does not exist, *educational sciences* [4] where an efficient nano-manipulator could enrich the theoretical descriptions of the phenomenon by a direct and sensorial approach of the nano-sciences, *physics* [5] where no means to control a carbon nanotubes manipulation exists today, are only few examples from the widespread area of nano-manipulator applications.

Nanomanipulators, which exist today on the market, implement a direct coupling between the AFM and the force feedback device. In spite of the efficiency of this connexion, it is limited to specific and dedicated commands and running modes. Inserting a computer-assistant between the AFM and FFGD, opens new possibilities in programming the AFM running modes as well as in the user control and assistance.

Worldwide researchers have started to create different systems in order to allow the experimentalist to manipulate at a nano-scale. Among them, a group from the Institute of Industrial Science, University of Tokyo [2] have designed a tele-manipulation device, one degree of freedom model. As far environment, they have used a real-time simulated nano-scene and 1-DOF force-feedback human interface that makes sensing the forces existing in the virtual scene. Being a complete virtual tool and tested only for liquid surfaces, their instrument is quite restrictive in applications.

One of the tele-manipulation systems, the Phantom system [6] was realised by Sensable, SA at University of North Carolina (UNC). Their device has good dynamic performances (response time, amplitude of returned force, etc.) but they are not sufficient to perform an accurate nano-manipulation and they are not associated with sensorial rendering and psychophysical measurements. Like UNC researchers, VRAI group [7] has developed a force-feedback device, the Delta Haptic Device (DHD), providing forces up to 25N through a large cylindrical working volume (30cm diameter, 30cm length). According their properties, both DHD and UNC devices are designed only as manipulators. They have no associations between the simple and direct manipulation chain and a stage of modelling, simulation and virtual emulation of the nano-scenes.

Another trial in designing a nano-manipulator is the creation of PicoAngler Tool by Digital Instrument, VEECO Metrology Group [8], which allows the user to manually explore tip-sample interactions and to feel the force of interaction via its force-feedback feature. The applications of this device developed especially for force spectroscopy limit the research field at molecular biology.

Thus, building a nano-manipulator as an independent workstation, which integrates a force sensor at the nanometre scale (the AFM tip) and an interface for experimentalist that will allow him to act in real time and to use all his cognitive capabilities (senses, knowledge, learning) in the nano-world is a new chalenge.

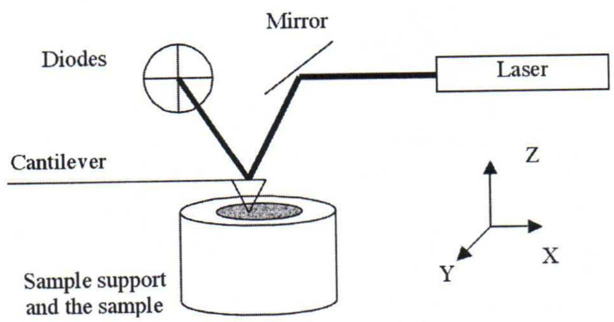

Fig. 1 AFM topology

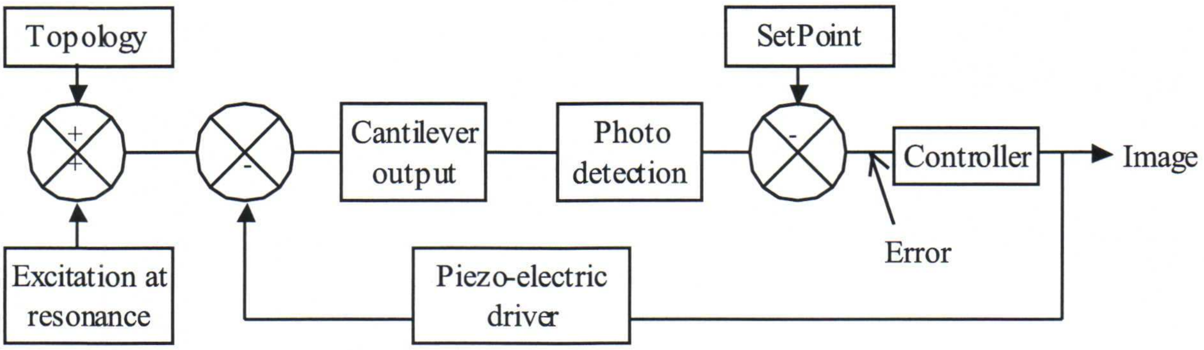

Fig. 2 Feedback loop for AFM in contact mode

Our project intends to offer a new and complete multi-sensory representation of the nano-world phenomena in the macroscopic universe.

The connection between an AFM and a FFGD allowing the experimentalist to feel the phenomena existing in the nano-world and to act on the AFM piezo element as well as the nano-scene virtual models are presented in this paper.

2. Instrumental chain

The development of a true, efficient, usable nano-manipulator based on Atomic Force Microscopy requires first, the acquisition and processing of high quality measured information, and secondly, the treatment of this information to create a perception/action scheme (human *presence*) in the nano-world.

The AFM topology presented in Fig. 1 assumes a laser source sending a beam on the backside of the cantilever, which reflects it in a four segments photodiode. Thus, the tip movements are transmitted to the cantilever, and then, the up and down cantilever movements are transformed in light beam movements across the surface of the photo-detector. The output of the photo-detector is directly proportional to the motion of the cantilever.

An AFM in contact mode operates by scanning the tip attached to the end of the cantilever across a surface while monitoring the change in cantilever deflection with the split photodiode detector. In this case, the feedback loop presented in Fig. 2 maintains a constant deflection between cantilever and the sample by vertically moving the scanner at each (x,y) data point to keep the "SetPoint" deflection.

The developed instrumental chain includes a Real-Time Work Station between the AFM and the FFGD, presented on the global scheme in Fig. 3.

An electronic board is designed and implemented to transfer the information between AFM and Real-Time Work Station (RTWS). This electronic board processes the signals by filtering and converting them from analogical to numerical form. Data transfer from Real-Time Work Station to AFM is presented in Fig. 4.

The commands sent by the RTWS, the electrical current values corresponding to force intensities are transformed in voltage values and applied to a BNC output. These signals are connected in a serial configuration with the signal that commands the piezo element of the AFM. For limiting the noise, this additional voltage is applied to Z_Rtn input of the AFM electronic block. The switch from Fig. 4 allows operating the AFM in a classical configuration, interrupting the RTWS link. Thus, a maximum voltage of 15V is added or subtracted to/from the voltage that command the piezo element, 300V, the maximum value. In terms of piezo displacement, an interval of 300 nm is obtained from a total displacement of 3μm. In reverse, the data transfer from AFM to RTWS is represented in Fig. 4.

The cantilever deflection is the signal to be transmitted to the RTWS. To obtain this signal, a subtraction of the AFM diodes signals (B-D)-(A-C) is necessary and is realized by an instrumentation amplifier AD624 illustrated in Fig. 4. A low-pass filter and an amplifier are used then to reduce the output impedance of the designed circuit. Voltages of 1 or 2V are transmitted, thus to the RTWS.

The information exchanged between AFM and RTWS is transfered further to the FFGD and so, a human operator can feel in his fingers the force intensity. The FFGD characteristics determine the performances of the human/machine interface and implicitly, the nano-manipulation success. The used FFGD is a manipulator [9] composed from independent pieces, one per degree of freedom as it can be seen in Fig. 5.

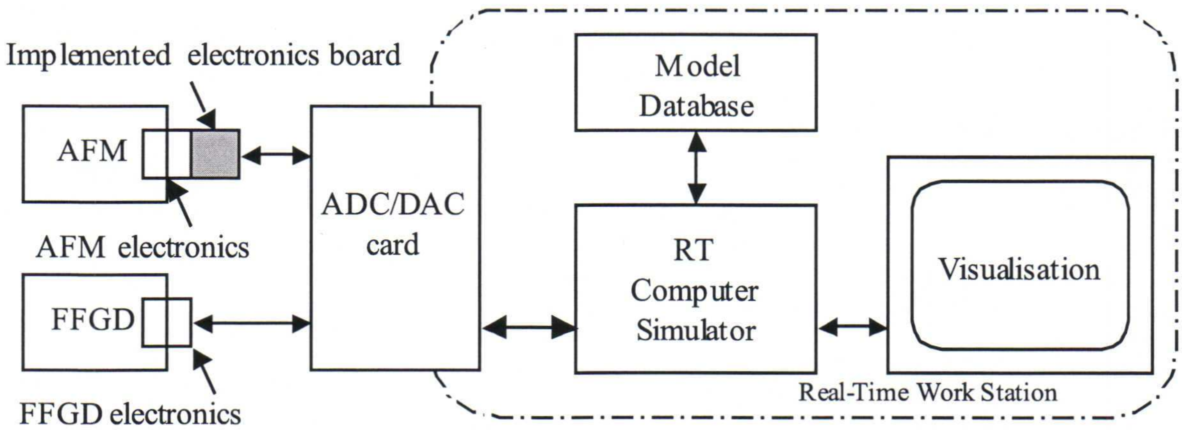

Fig. 3 Global scheme of the AFM - Real-Time Work station - FFGD

Each of these pieces is controlled by an electromagnetic actuator, is linked to a high-resolution (2μm) position encoder and is characterized by 20 mm vertical displacement and 10 kHz cutting frequency. One FFGD piece supports a force of 50N in a permanent regime and a force of 200 N in a transitory regime, having a maximum speed of 2 m/s.

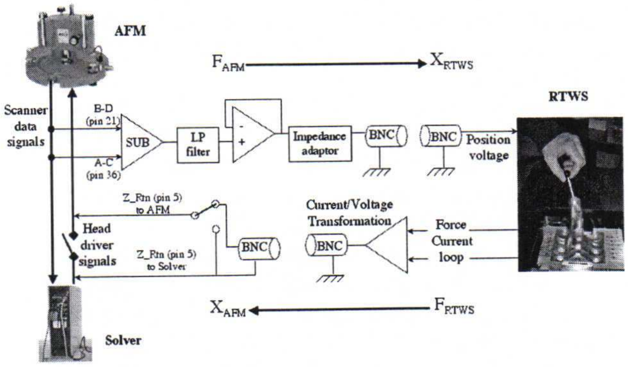

Fig. 4 Signal transfer between RTWS and AFM

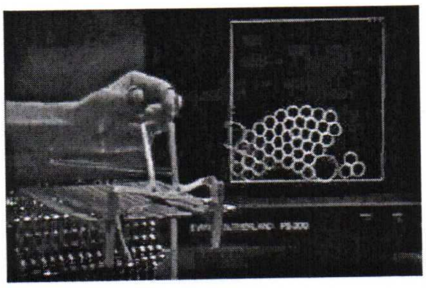

Fig. 5 The Force Feedback Gestural Device

3. Results and discussions

We connect the AFM with the FFGD by intercalating a real-time processor between these two devices (Fig. 6). The real-time processor allows physical modelling with 3kHz bandwidth for the force feedback sensitivity. In order to obtain the system functionality independent of the signal processing and commands executed by the builder solver, the coupling imposes the design of the electronic card and computer considerations described below.

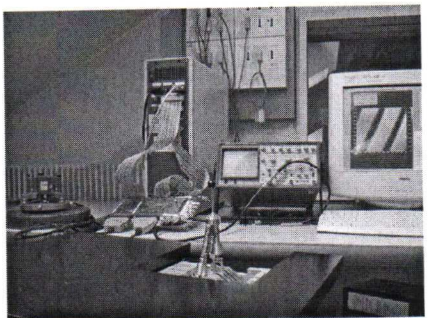

Fig. 6 AFM, Real Time Work Station, and FFGD chain

In order to validate our results with regard to the original prints, we preserve the electronic system of the builder and the PC acquisition card. The analogical signals of the AFM head are intercepted, treated and transmitted to the real-time processor architecture by a home-developed acquisition card illustrated in Fig. 4.

This treatment allows obtaining a signal shape according to the functional and regulation modes of the AFM. Due to the realized instrumental chain, an experimentalist can command the AFM piezo element position and, thus the tip movement by acting on the FFGD pieces as is illustrated in Fig. 7.

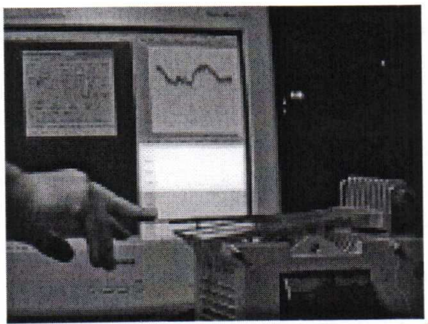

Fig. 7 AFM piezo element commanded by the experimentalist

In reverse, the data transfer from the AFM to the FFGD, represented in Fig. 8, allows the experimentalist to feel the approach, respectively the retract forces existing between the AFM tip and the sample surface.

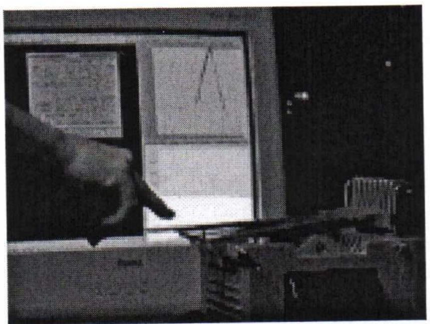

Fig. 8 Tip-surface approach forces transferred to the experimentalist

In parallel with technical developments we have studied the constituents of the nano-manipulator from a *modelling and virtual reality* point of view. We have defined different models that reconstruct at the human scale the interactions between sample surfaces and AFM tips at the nanometre scale.

To analyze the critical behaviour of nano-objects deposed on a sample surface, we have realized a first model that simulates the Van-Der-Waals interactions by creating a virtual tip, which is connected to a piezo element by a spring and which interacts with the surface. The hysteresis effect, characteristic to an approach-retract phenomenon can be detect and feel by the experimentalist. A more elaborate model illustrated in Fig. 9 implements the *two-wheeler* metaphor, which allows moving, lifting and bringing an object on the surface.

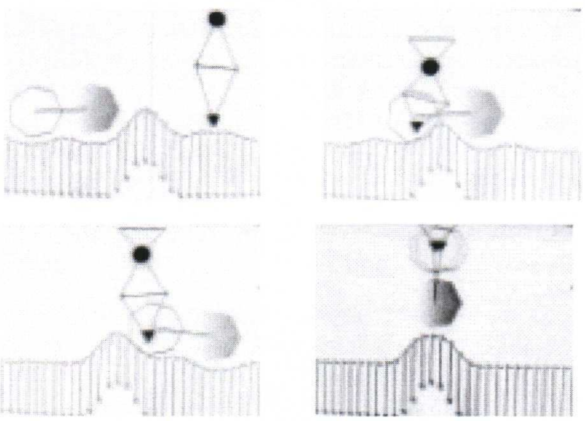

Fig. 9 Model for moving and grasping a nano-object on a surface

This model provides to the user information about the characteristics of the AFM tip, in particular if its cohesion with the object to be moved is strong enough for realizing such operations. Thus, we can put in evidence some delicate situations that appear in real actions, and obviously at different scale rates.

4. Conclusions

An AFM link with a FFGD assisted by a Real-Time simulation engine as well as physical models for the phenomena existing in a nano-scene are presented in this paper. The first results we have obtained are determinant for the next developments concerning the multi-sensory nano-manipulator.

The user commands the AFM tip thanks to the FFGD control lever and he can feel the cohesive forces amplified at the Newton order (by a 10^9 factor).

The virtual manipulations allow calibrating the real manipulations in a non-destructive way, and offer a contact between the user and the nano-world, with a force feedback, visual and auditory representation.

The designed architecture deals not only with a scale-changing command, but also with a simulation platform, which allows reconstructing the nanometre world in a virtual system, and includes an estimation of the operator possibilities, his capacities face to this environment. Feeling the *sticking and takeoff* phenomenon as a measure of the approach-retract interaction of the AFM tip with the surface shows the extent of the capabilities, which can be henceforth exploited for the future developments.

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